Energy Efficiency, California Building Energy Use, and Greenhouse Gas Emissions Mitigation for the 21st Century

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OUTLINE

This talk will present analysis of the long-term contribution of end-use energy efficiency to climate mitigation.

Context

Stabilizing Climate

Analysis Approach – Integrated Assessment

Systems Approach over 100 years

CA in Context: A First Step

Long-Term CA Building Energy Scenarios

US Value of Energy Efficiency

Contribution of End-Use Efficiency to Lowering Mitigation Costs

Conclusions

Additional Slides

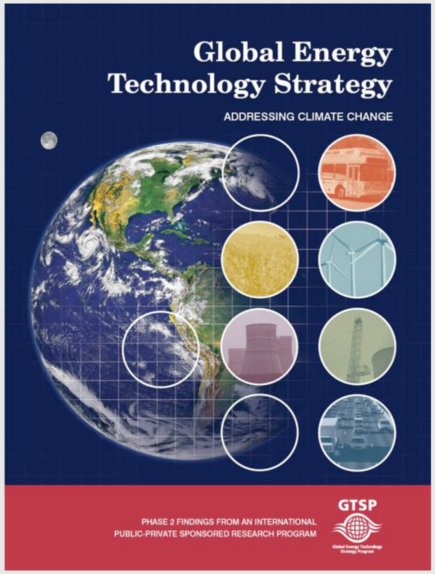
Funders
California Energy Commission
DoE Office of EERE
GTSP

Motivation

While previous aggregate long-term analysis demonstrated that the cost savings due to efficiency is potentially very large, we need to be able to examine the role of specific groups of technologies in order to quantify this potential.

Context: Findings from the Global Energy Technology Strategy Program

Copies of the Report are Available



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Climate Policy Context: General Principles

Stabilization of CO_2 concentrations requires emissions that eventually decrease toward zero

- Stabilization of greenhouse gas **concentrations** is the goal of the Framework Convention on Climate Change
- Stabilizing CO_2 **concentrations** at any level means that **global** CO_2 emissions must peak and then decline forever.

Substantial changes in the global energy system will be needed to stabilize climate.

- A **price on carbon** is required to stabilize emissions. Fossil-fuel resources are too abundant to not be used in a fashion that freely vents carbon otherwise.

The role of technology is to control costs

- The value of a technology for climate mitigation needs to be considered over the long term and globally, and depends on the availability of other technologies.

IAM's: Tools for Long-Term Analysis

Integrated assessment models (IAMs)

- Combine information from numerous disciplines into one framework.
- Each model makes different tradeoffs between completeness and complexity, depending on its purpose.

IA Models Are Not "Truth Machines"

- IA models are not predictive — we can't "forecast" many of the most important factors such as technology or human socio-economic developments.

IA Models Are Tools, useful to examine:

- possible futures with different assumptions for energy technologies, economic growth rates, etc. *(thereby producing emission scenarios)*
- the relative costs of GHG emissions reductions under different scenarios for technology and policy assumptions
- what are the important linkages?
- where are the lever points?

The O^{bj}ECTS Framework

The Object-oriented Energy, Climate, and Technology Systems (O^{bj}ECTS) Framework uses a modular, data-driven architecture to model energy and agricultural systems.

- Implemented in C++
- Enables detail where needed
- Input data determines the market structure, sector definitions, fuels, and linkages.

The O^{bj}ECTS MiniCAM implementation

- Long-term model of energy, agriculture, land-use, and climate
- Same basic partial-equilibrium equation structure.
- Substantially more flexibility in structure of the energy system.
- Now contains detailed representations of end-uses, renewables, and vintaged technologies.

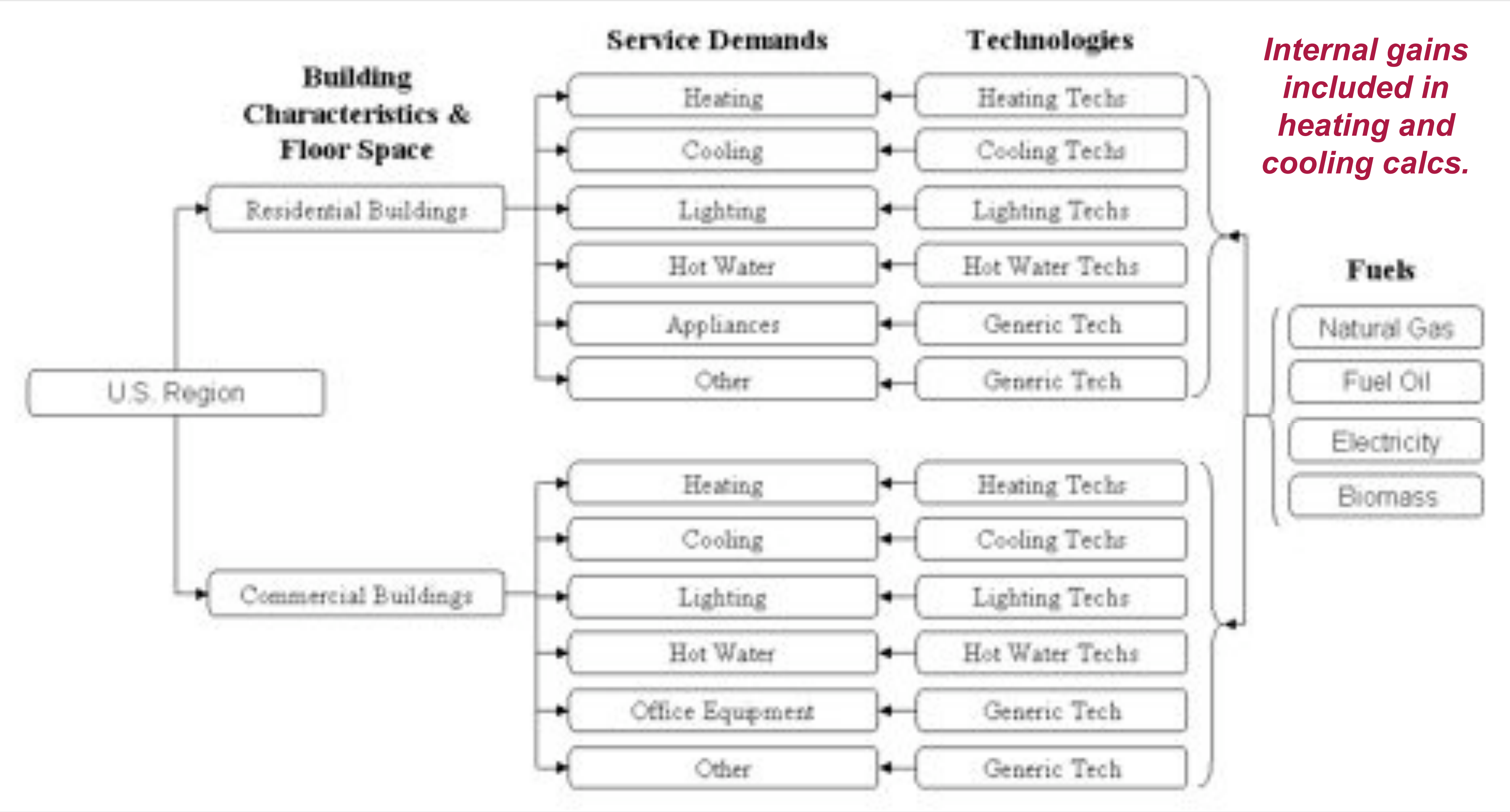
As an integrated model, O^{bj}ECTS MiniCAM incorporates endogenous energy, agricultural, and carbon prices, supplies, and demands.

Modeling Energy End Use Technologies

- Have developed detailed end-use sector models
  - Completed U.S. versions of transportation, buildings, & industry; and California buildings
- The Details Matter
  - Evolution of underlying service demands
    - Growth in information and "other" technologies in buildings, air travel in transportation
  - Switching to lower carbon fuels
    - There are ample opportunities to electrify the buildings sector
    - Process heat provides a floor in the industrial sector
    - Technology drives the opportunities in the transportation sector
  - Opportunities for efficiency gains vary by application (e.g., existing efficiency is high in boilers and motors)
- Detail is embedded in a global, long-term model
  - Trace the impacts of individual end-use technologies (e.g., solid-state lighting) through to energy transformation, emissions, concentrations, and radiative forcing, and climate change.
  - Endogenous energy prices and feedbacks

Approach to U.S. and California Building Sectors

The model structure is based on **services** and the technologies that might supply these services.



Internal gains included in heating and cooling calcs.

* *Modeling of some services is subject to substantial data limitations.*

Long-Term California Building Energy Demand

A reference case long-term scenario of California building energy consumption was developed using

- A representative residential and commercial building sector
- As with our U.S. model, intended to examine long-term trends
- Allows consistent, simultaneous calculation of California and "rest of U.S." building sector and the response to a carbon policy

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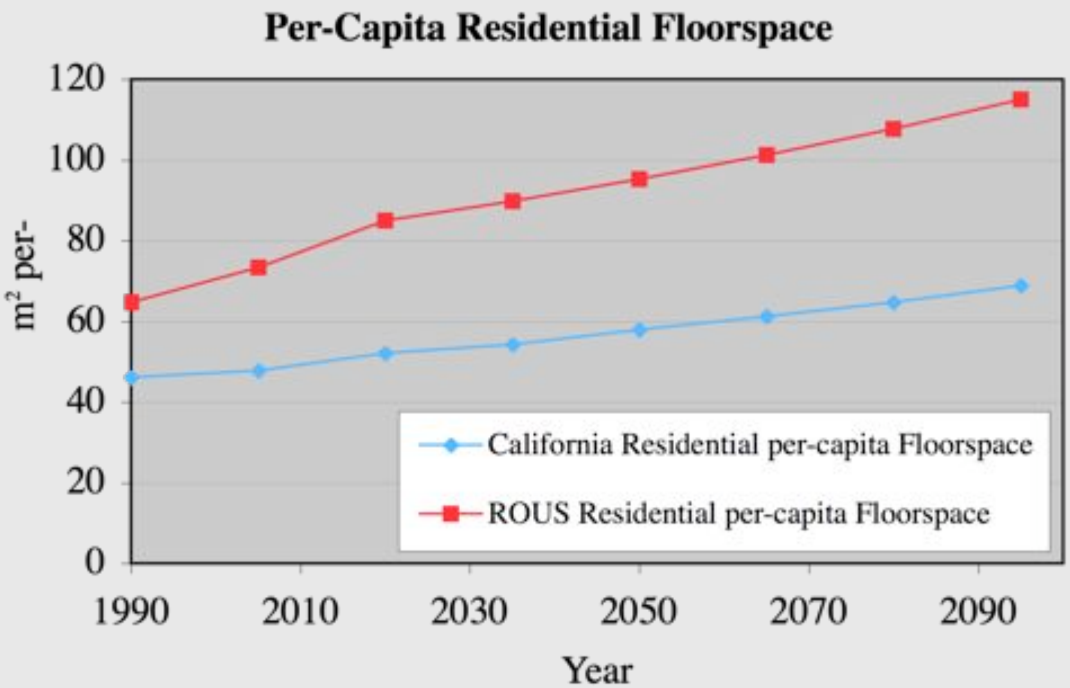
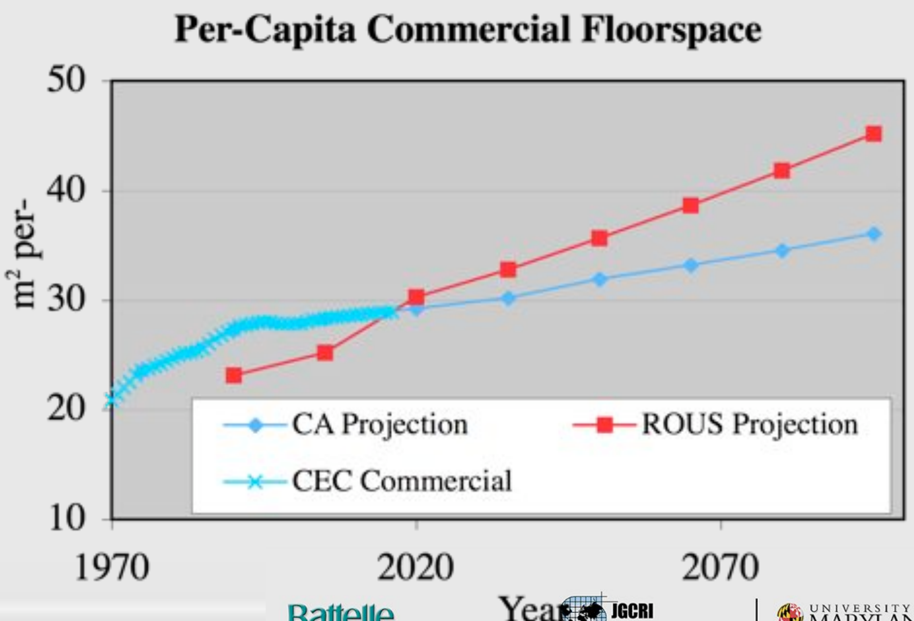
►Input Assumptions

- CA labor-productivity growth rates (state projections,merging to national rates after 2050)
- CA population growth (state + U.S. Census projections)
- Technology performance + cost assumptions

Our building parameterization requires absolute physical efficiencies for heating, cooling, and lighting, which are not always available. Further work is required to reconcile existing data for California and the United States.

Floorspace Scenarios





Floorspace assumptions are the foundation of a building scenario.

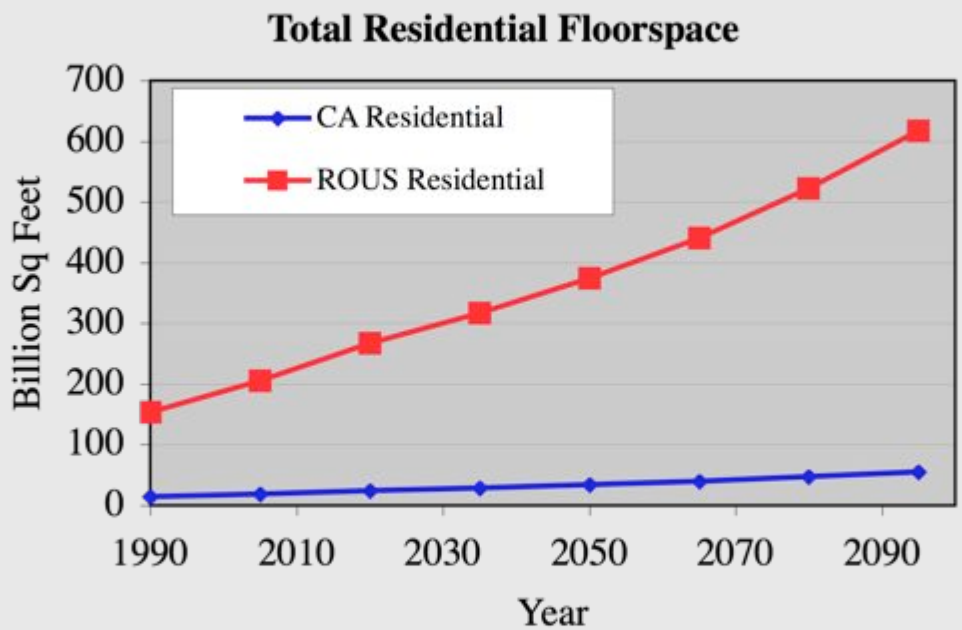
There is a strong historical record of increasing per-capita floor space.

California has much smaller per-capita residential floorspace, apparently, with a slower growth rate.

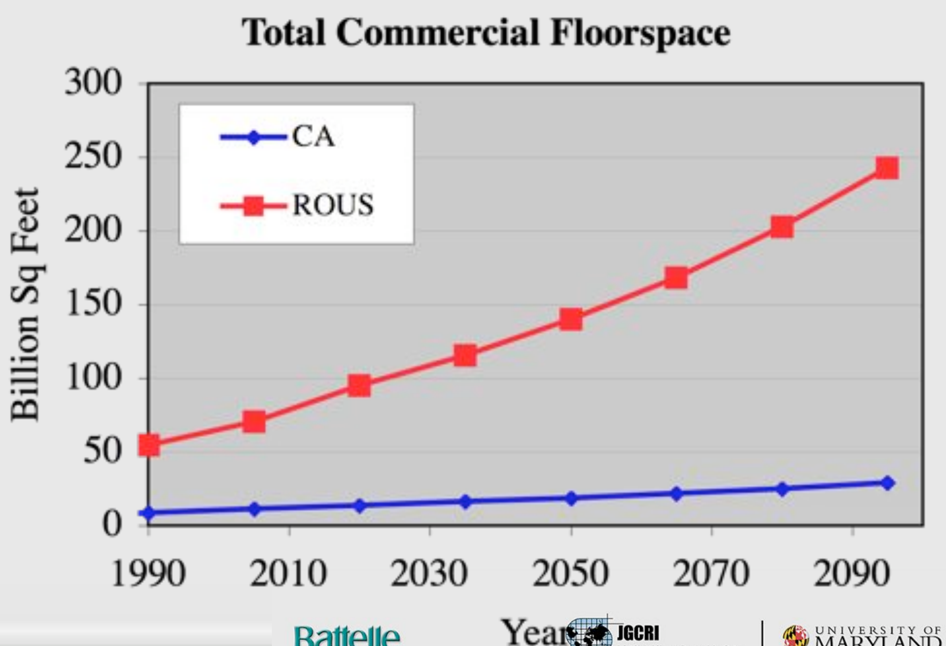
While commercial building comparisons are particularly prone to uncertainty due to definitional issues, it appears that California is comparable to the rest of the US in per-capita commercial floorspace, although the growth rate may be much less.

ROUS = Rest of US

California Building Floorspace



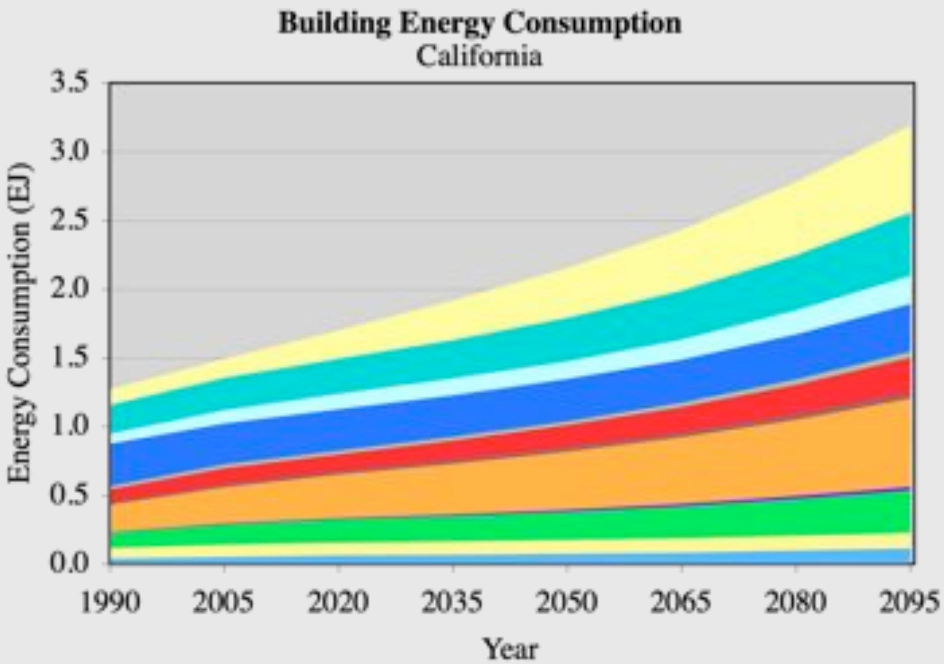
While the per-capita growth rate of residential floor space in California is smaller than that in the rest of the United States, **the growth rate for total floorspace is about the same — a factor of 3 over the next 90 years**.

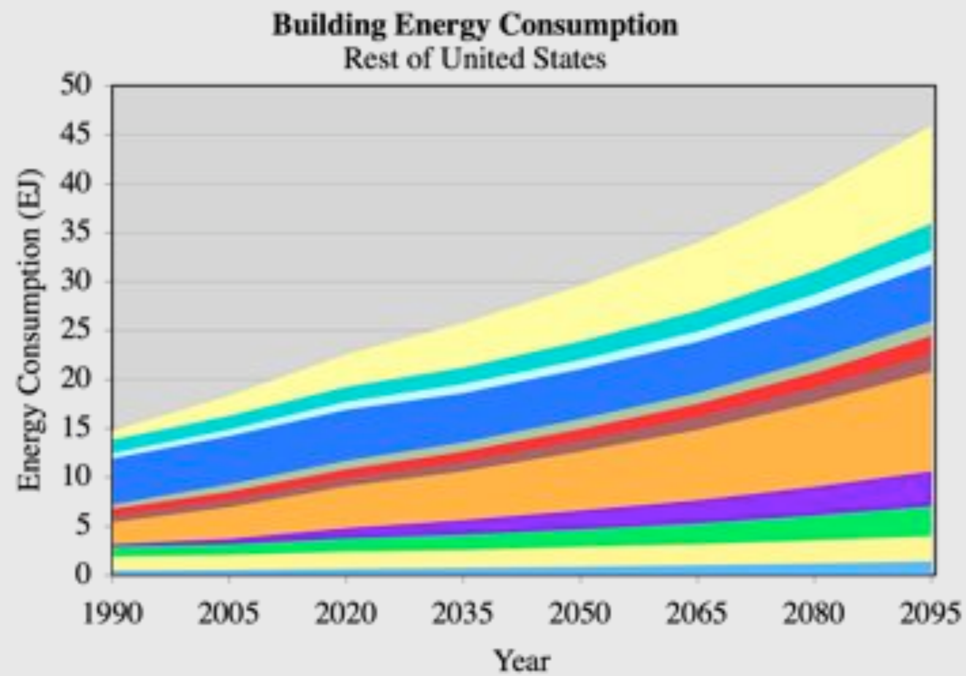


The growth rate of total commercial floorspace in CA is lower than that in the rest of the US in this projection.

A CA version of our end-use buildings model was embedded in our global model

Building Energy





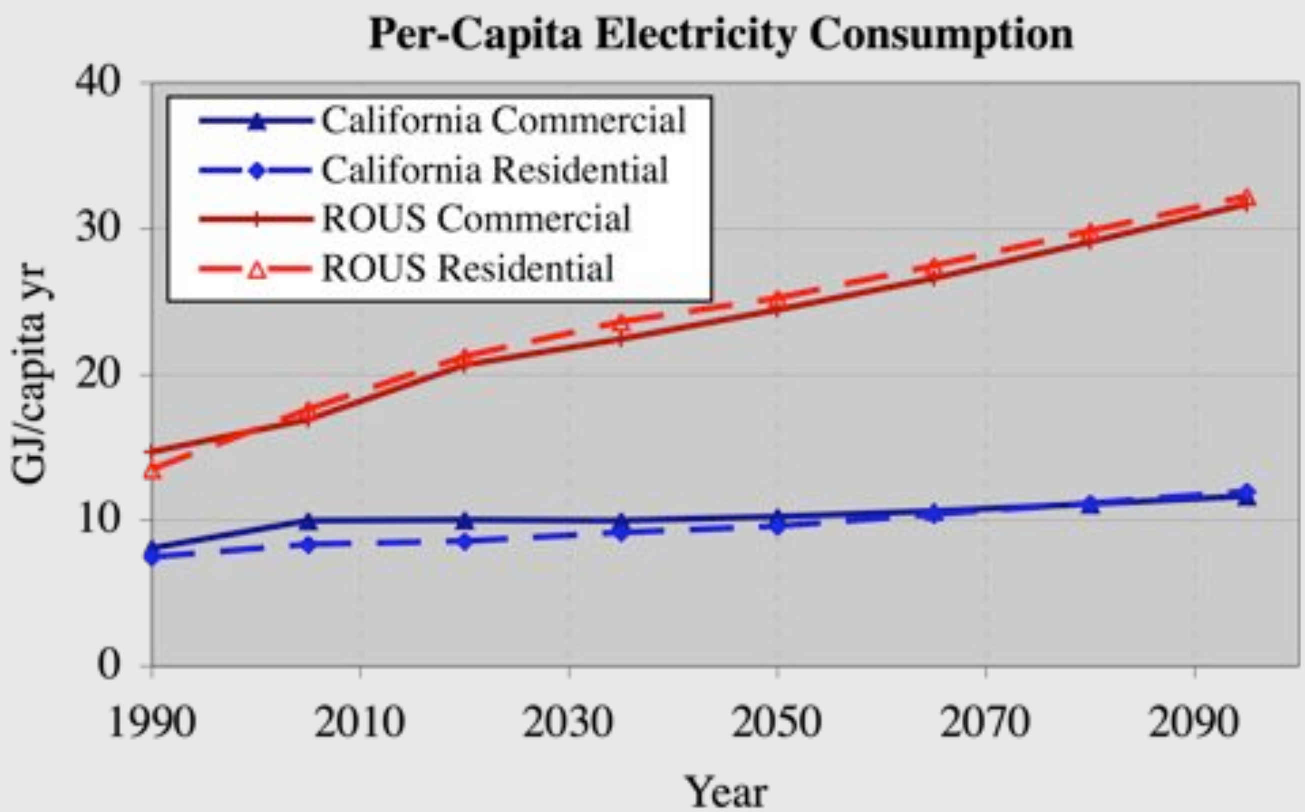
- Current energy use profile is different, but not dramatically so.
- Heating and cooling energy smaller per m^2, as expected due to difference in HDD and CDD between CA and ROUS.
    - ≈Residential cooling still half of what would be expected, however
- Per capita residential water heating similar
- Some significant differences in commercial sector
- **“Other” demands are dominate in the long-term**

The “rest” of US is not the same as CA.

Unfortunately nether are the data sources.

residential others
residential water heating
residential lighting
residential heating
residential cooling
residential appliances
commercial water heating
commercial others
commercial office equipment
commercial lighting
commercial heating
commercial cooling

CA Electricity Use



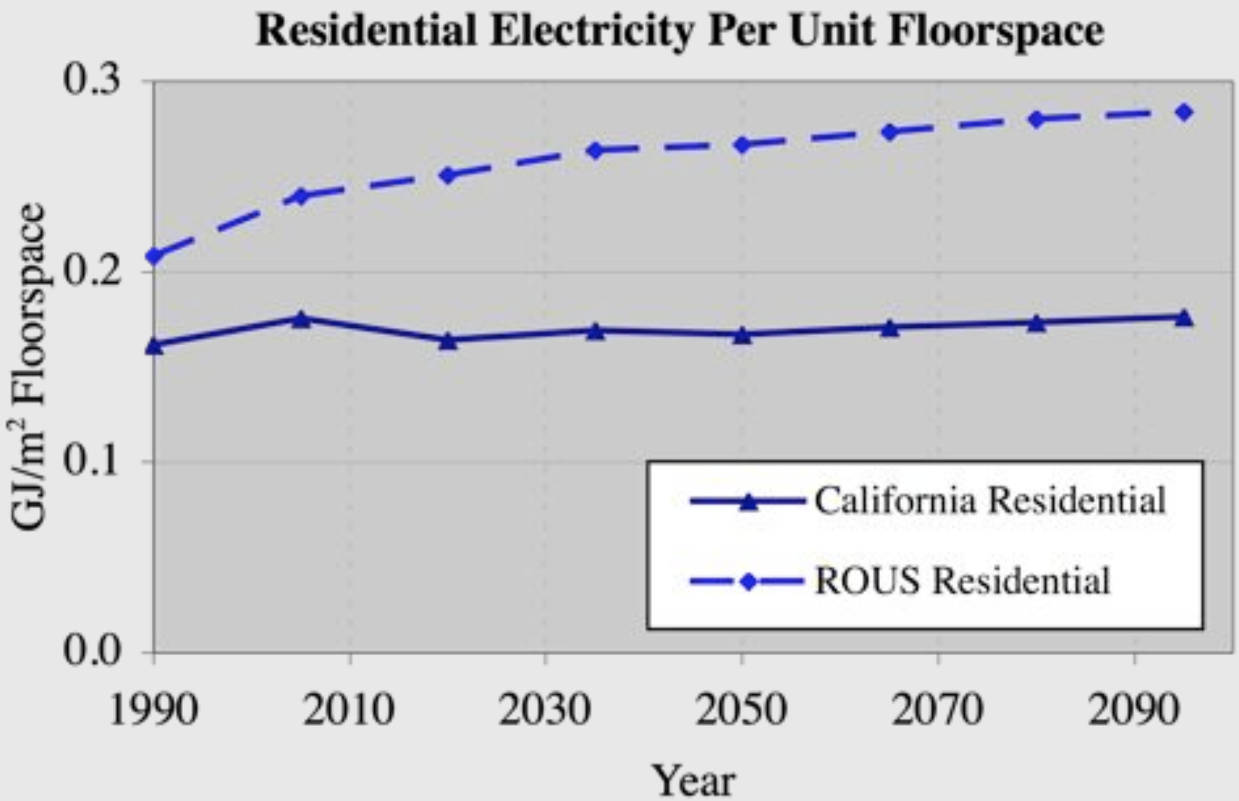
California per-capita electricity consumption increases slightly over the century.

Per-capita electricity consumption increases substantially in the rest of the U.S.

Over the next 90 years, **total electricity** demand (not per-capita) increases by a factor of 2.6 in California and 3.6 in the rest of the United States.

While California also faces the challenge of increasing electricity demand, efficiency measures and lower per-capita floorspace growth reduce the magnitude of this challenge relative to the rest of the United States.

CA Electricity Use



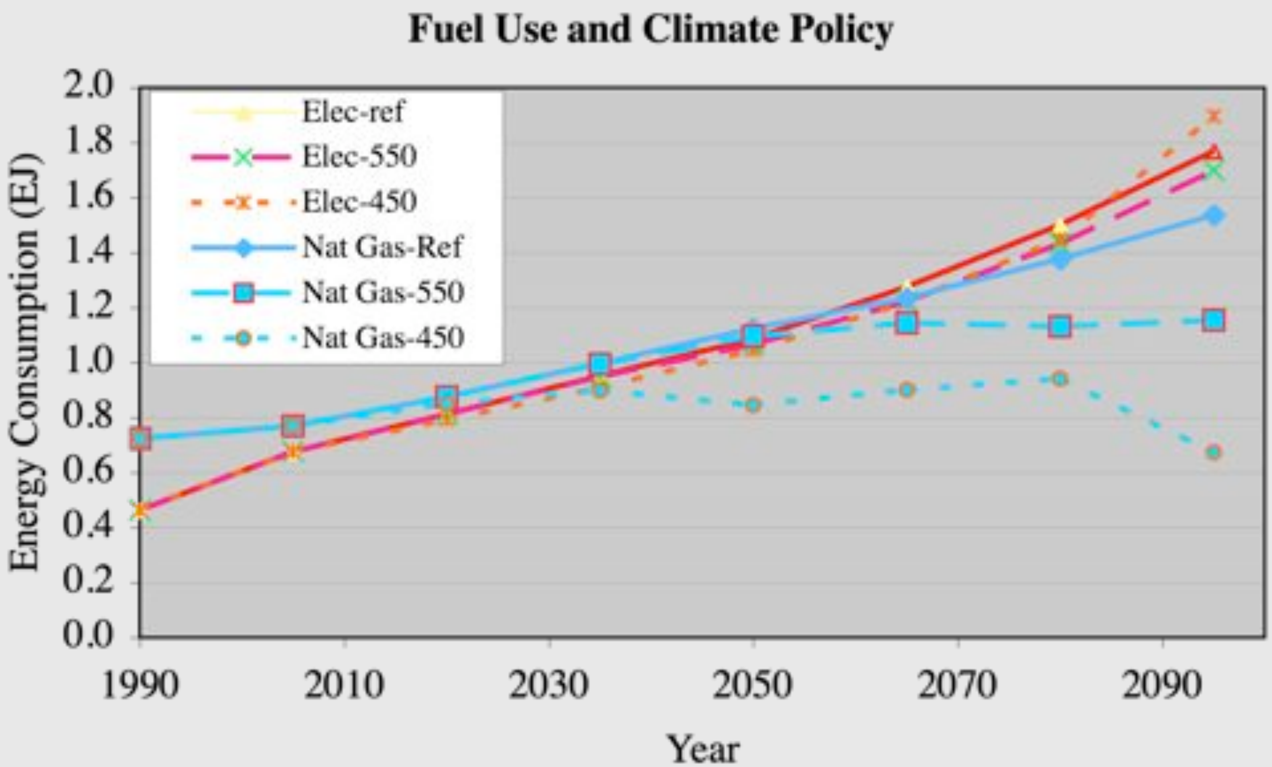
California residential energy consumption remains relatively constant per unit floorspace.

While California per-capita residential electricity consumption is half that of the United States, much of that difference is due to differences in floorspace per person.

On a per-unit floorspace basis, California has about 25% lower energy consumption as compared to the rest of the country.

Part of the difference in trend over time is due to different heating and cooling loads.

CA Building Energy and Climate Policy



Electricity consumption changes are small due to counteracting forces: 1) substitution for gas (increase) and 2) decreased service demand due to higher energy prices (decrease).

From the end-use buildings perspective, the primary result of a climate policy is a lower growth rate for the consumption of natural gas.

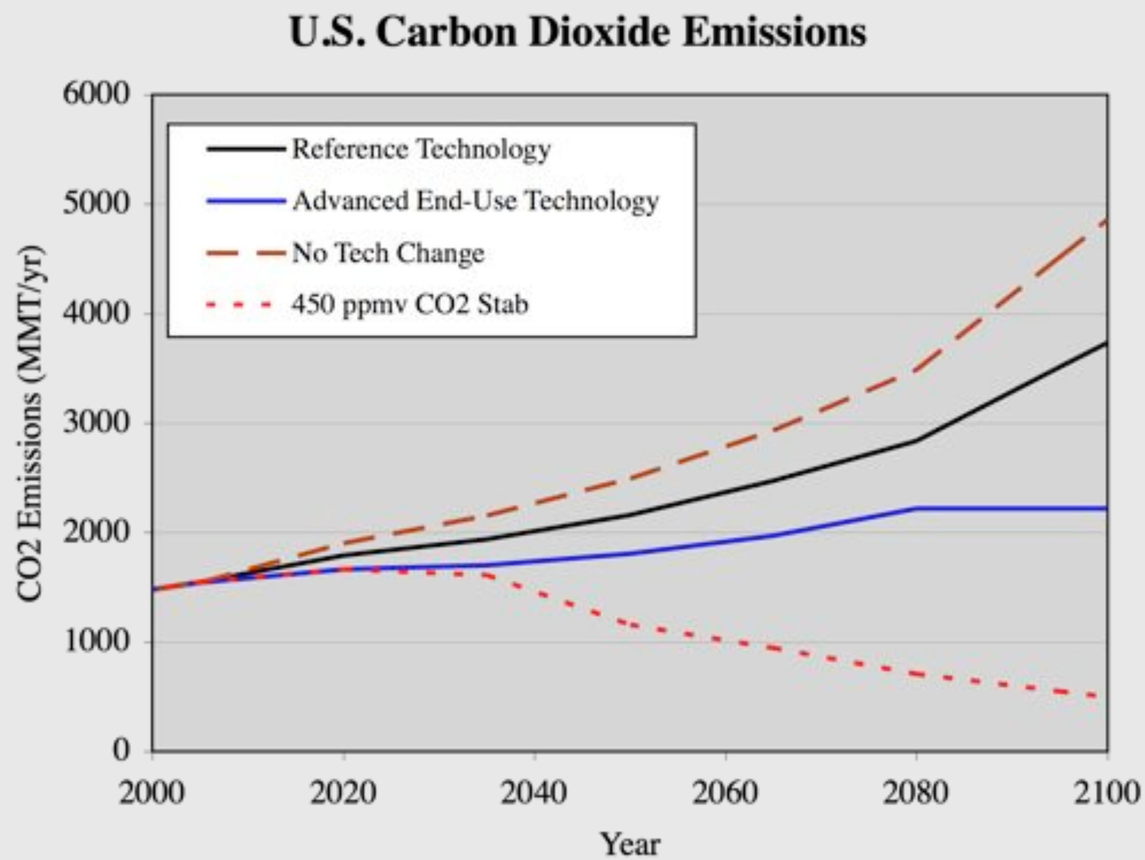
Value of Energy Efficiency in a Climate Context

Analysis Overview

We wish to determine the value of energy efficiency in terms of lowering the cost of meeting climate goals in the United States. Our analysis setup:

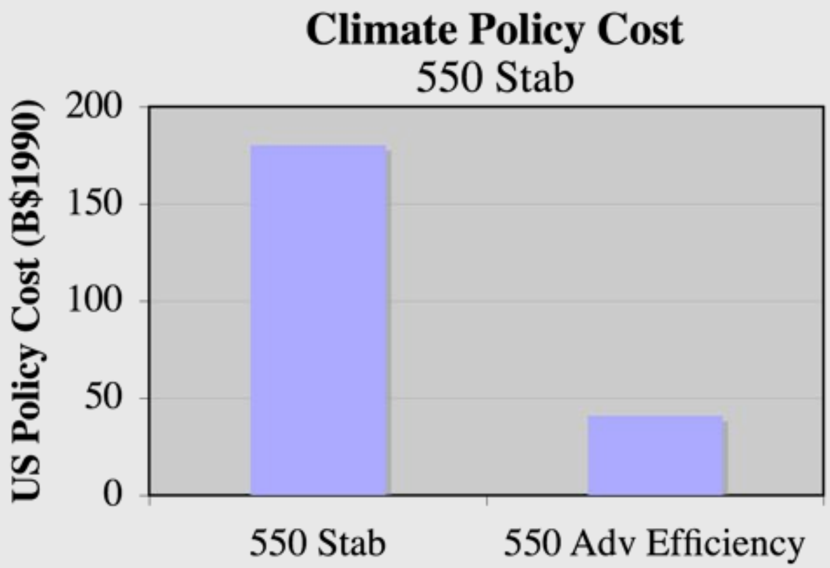
- Uses detailed end-use sectors in the US that have physical service demands (floorspace, passenger-km, etc) and specific categories of end-use technologies (natural gas or heat pump furnaces, etc.).
  - Residential Buildings
  - Commercial Buildings
  - Industry
  - Transportation
- Used CCSP globally constrained emissions to define US emissions constraints
  - US emissions to follow path found from global climate stabilization solution for both reference and advanced end-use technology cases
- U.S. costs of stabilization determined with reference and advanced suite of energy efficiency technologies
  - Reference case technologies follow evolutionary pathway with still substantial improvement over the century.
  - Advanced suite has further improvements and some additional technologies

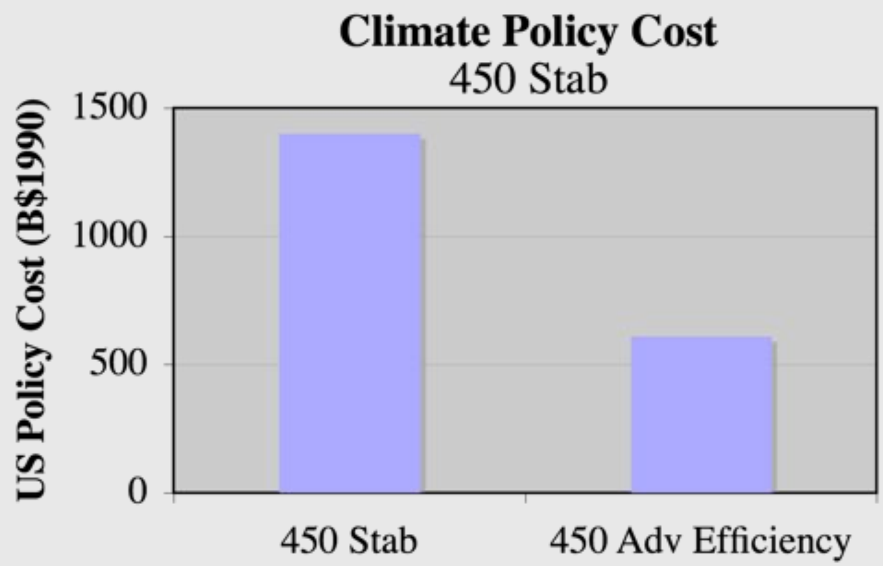
Carbon Dioxide Emissions



- Without the technological advances embodied in reference case end-use technologies, U.S carbon emissions would be 30% larger by the end of the century.
- Emissions under the advanced scenario increase much less.
- Even with these advances in end-use efficiency, however, carbon emissions do not fall and atmospheric CO_2 concentration would continue to increase.

Value of End-Use Technology





The figures show the total U.S. discounted climate policy cost with reference technology and the case with improved end-use energy efficiency.

The deployment of advanced energy efficiency technologies lowers the cost of achieving a climate policy by 55-75% as compared to the reference case. *(50-86% in the latest version of this analysis.)*

The relative value of efficiency is somewhat smaller for more stringent targets. For more stringent targets, emissions reductions are required earlier – which gives efficiency less time to deploy (although the effect of past efficiency policies is still present).

The absolute value is still much larger, however, given the overall higher costs of tighter targets.

**Cost defined as total discounted U.S. carbon payments.*

Summary Points

- Future energy demand trajectory in CA on a per-capita basis remains divergent from U.S., but total energy demands still grow substantially.
  - ⇒ *Further comparison of CA and rest of US would likely yield useful information on the potential of energy efficiency (this requires more detailed analysis of source data)*
  - ⇒ **Improved knowledge of historical trends and dynamics is needed!**
- "Other" plug loads may become a dominant end-use.
  - ⇒ *Internal gains from electric loads negate a portion of the building shell efficiency improvements with respect to reducing cooling loads*
- Energy efficiency policies can have a much larger impact on end-use energy demand than climate policies.
  - ⇒ *Electricity prices do not increase enough to induce large technology shifts in electric equipment.*
- Overall, enhanced energy efficiency has substantial value in a climate context.
  - ⇒ *A suite of energy efficiency improvements cut U.S. policy costs by 50-85%* ***(But we would have to have started yesterday… So some of this value is lost through delay.)***

Papers and Reports

ObjECTS framework description and detailed transportation end-use model

Kim, S.H., J. Edmonds, J. Lurz, S. J. Smith, and M. Wise (2006) The ObjECTS Framework for Integrated Assessment: Hybrid Modeling of Transportation *Energy Journal* (Special Issue #2) pp 51-80

Buildings model and U.S. analysis

Rong, F., L. Clarke, and S. J. Smith (2007) Climate Change and the Long-Term Evolution of the U.S. Buildings Sector. PNNL report. http://globalchange.umd.edu/

California and U.S. analysis

Smith SJ, P Kyle, MA Wise, LE Clarke, EM Rauch, SH Kim, JA Dirks, JD Dean, and DB Belzer (2007) California in a Climate Context: Long Term Scenarios of End-Use Efficiency & Renewable Energy (CEC - *in review*).

Industrial Sector Model and Analysis

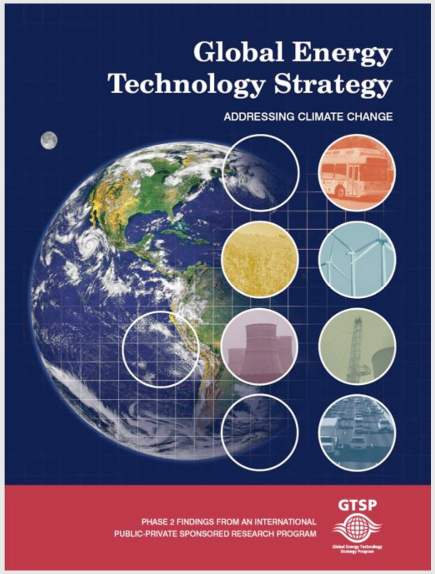
Wise, MA, P Sinha, and SJ Smith (2007). Long Term US Industrial Energy Use and Carbon Dioxide Emissions (*in preparation* - Sept 2007). http://globalchange.umd.edu/

Value of Energy Efficiency Technologies for Mitigating U.S. Carbon Emissions

In preparation (Oct 2007) http://globalchange.umd.edu/

Findings from the Global Energy Technology Strategy Program

Copies of the Report are Available



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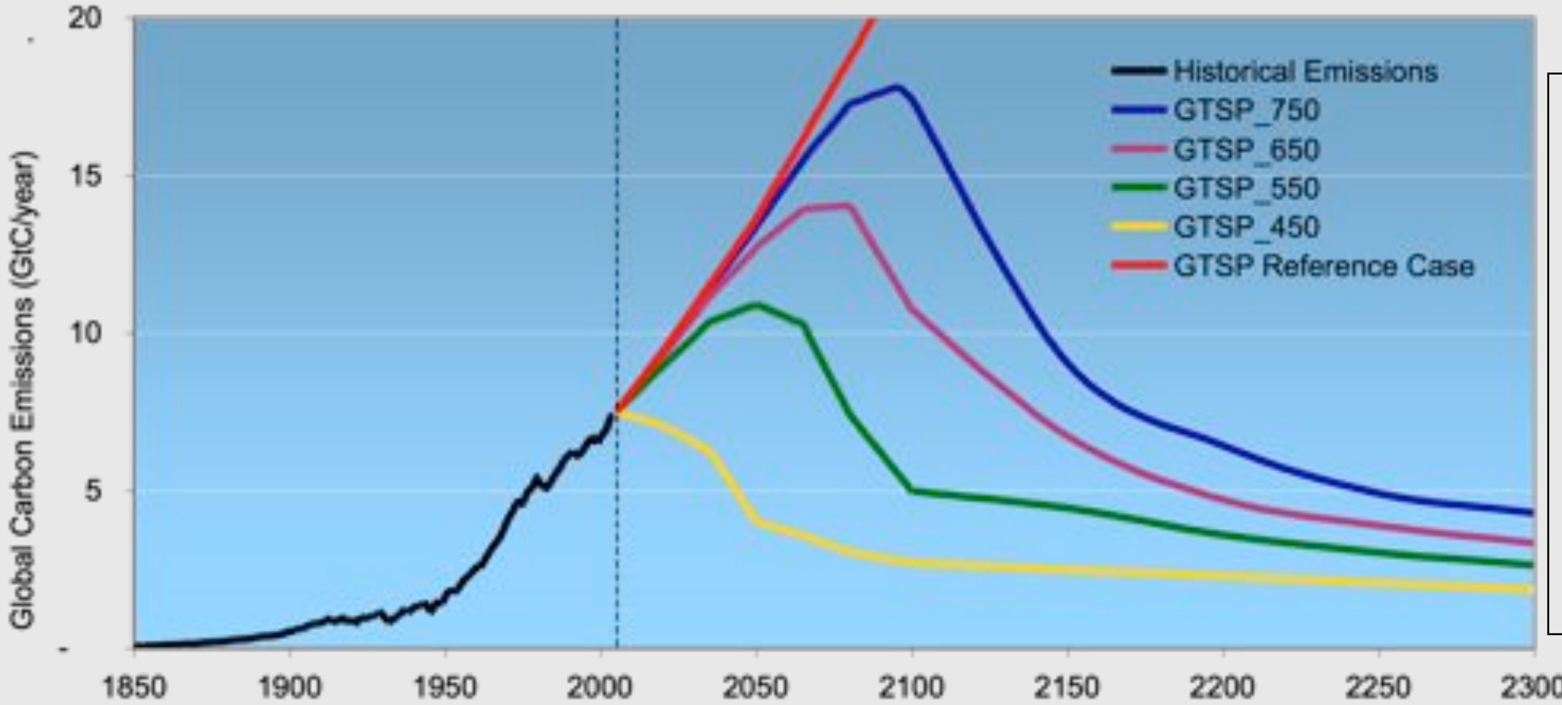
ADDITIONAL SLIDES

CONTEXT

Climate Stabilization: Emissions

Stabilization of CO_2 concentrations requires emissions that eventually decrease toward zero.

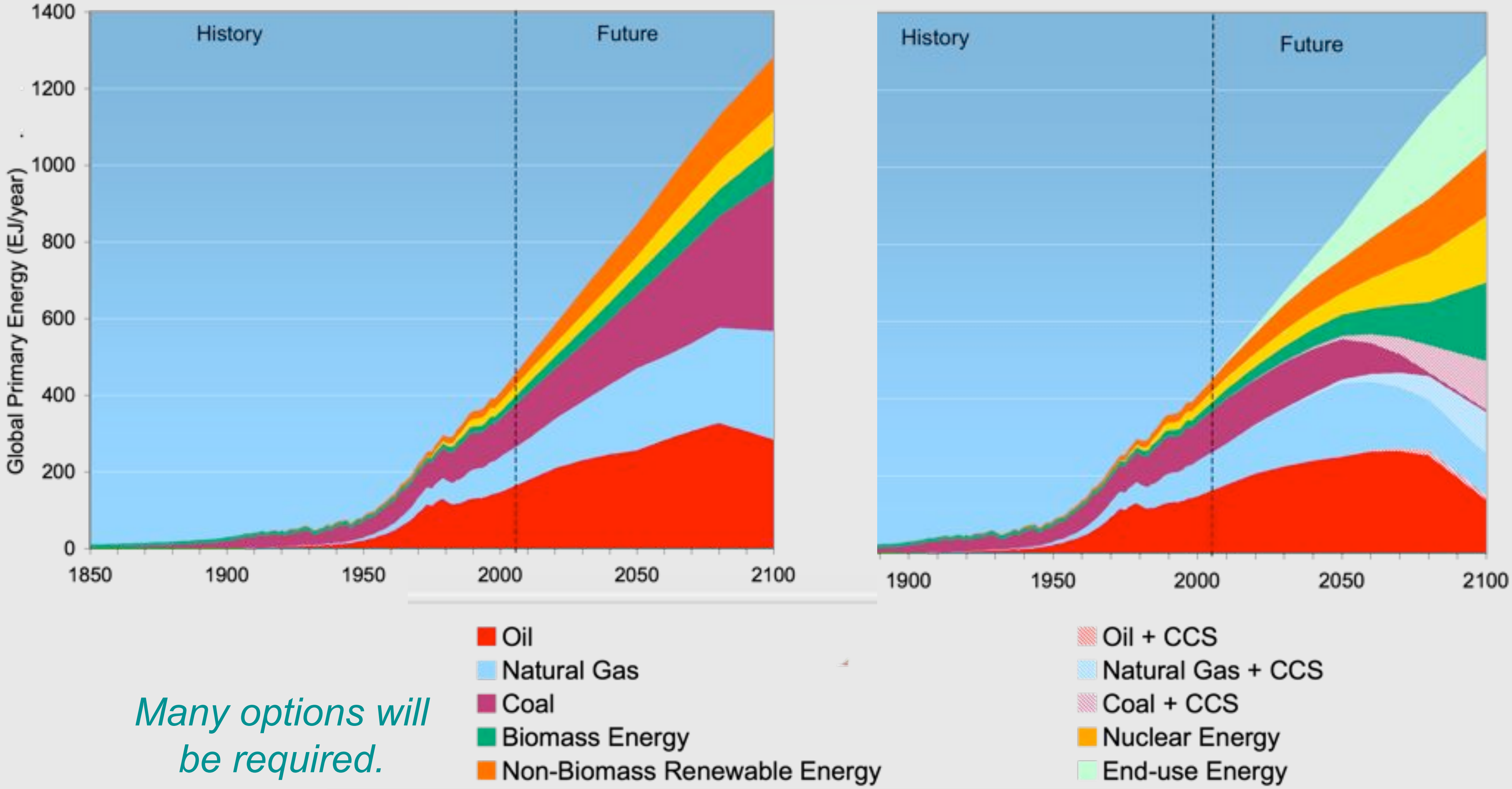


Concentration stabilization only bounds the level of future climate change. Significant climate change is still likely to occur. Adaptation to these changes will be needed.

- Stabilization of greenhouse gas **concentrations** is the goal of the Framework Convention on Climate Change.
- Stabilizing CO_2 **concentrations** at any level means that **global** CO_2 emissions must peak and then decline forever.

Climate Stabilization: Energy

Substantial changes in the global energy system will be needed to stabilize climate.

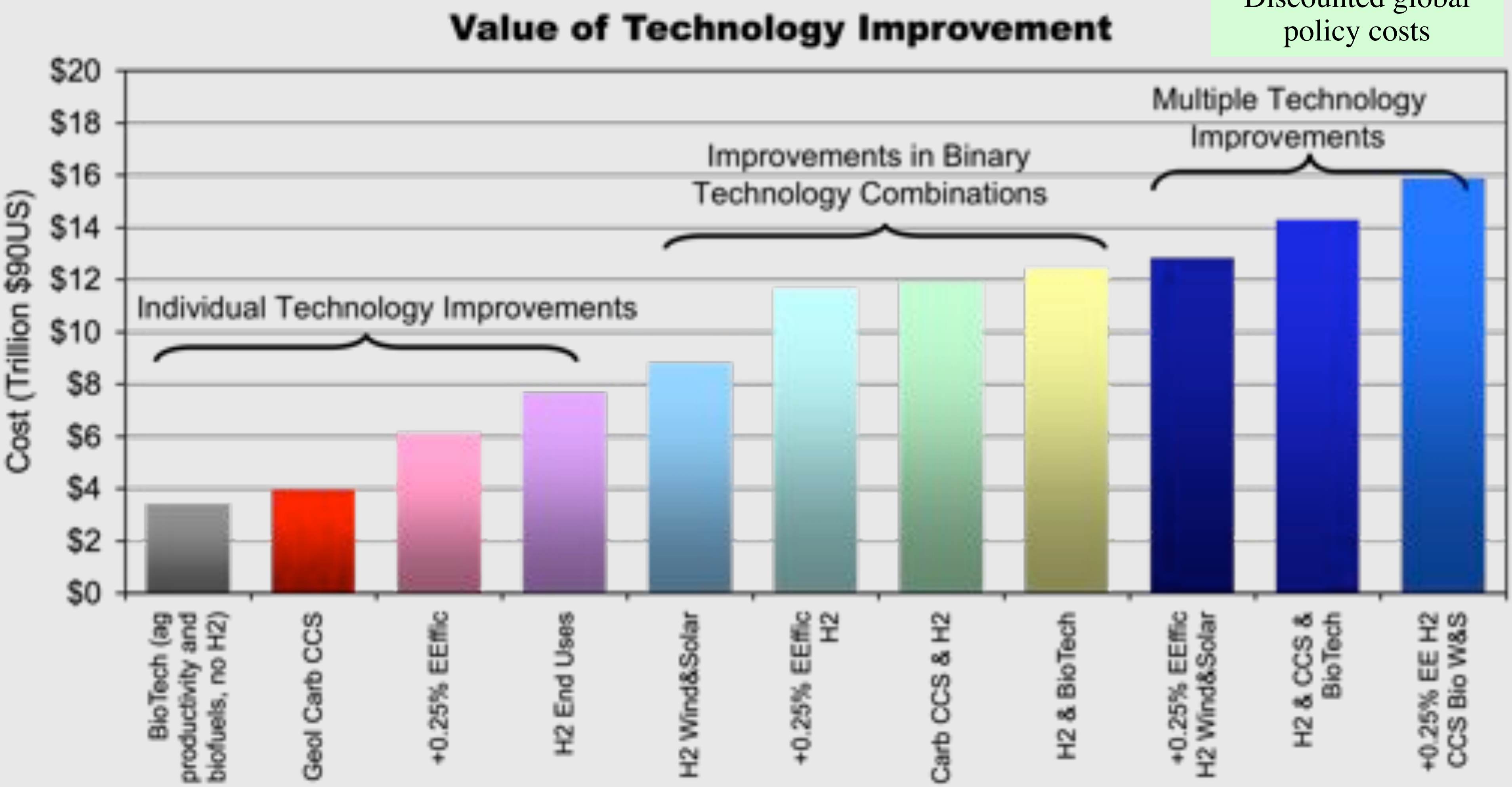


Many options will be required.

Edmonds and Smith (2006) “The Technology of Two Degrees” In: Avoiding Dangerous Climate Change (Cambridge University Press).

The role of technology is to control costs

Discounted global policy costs



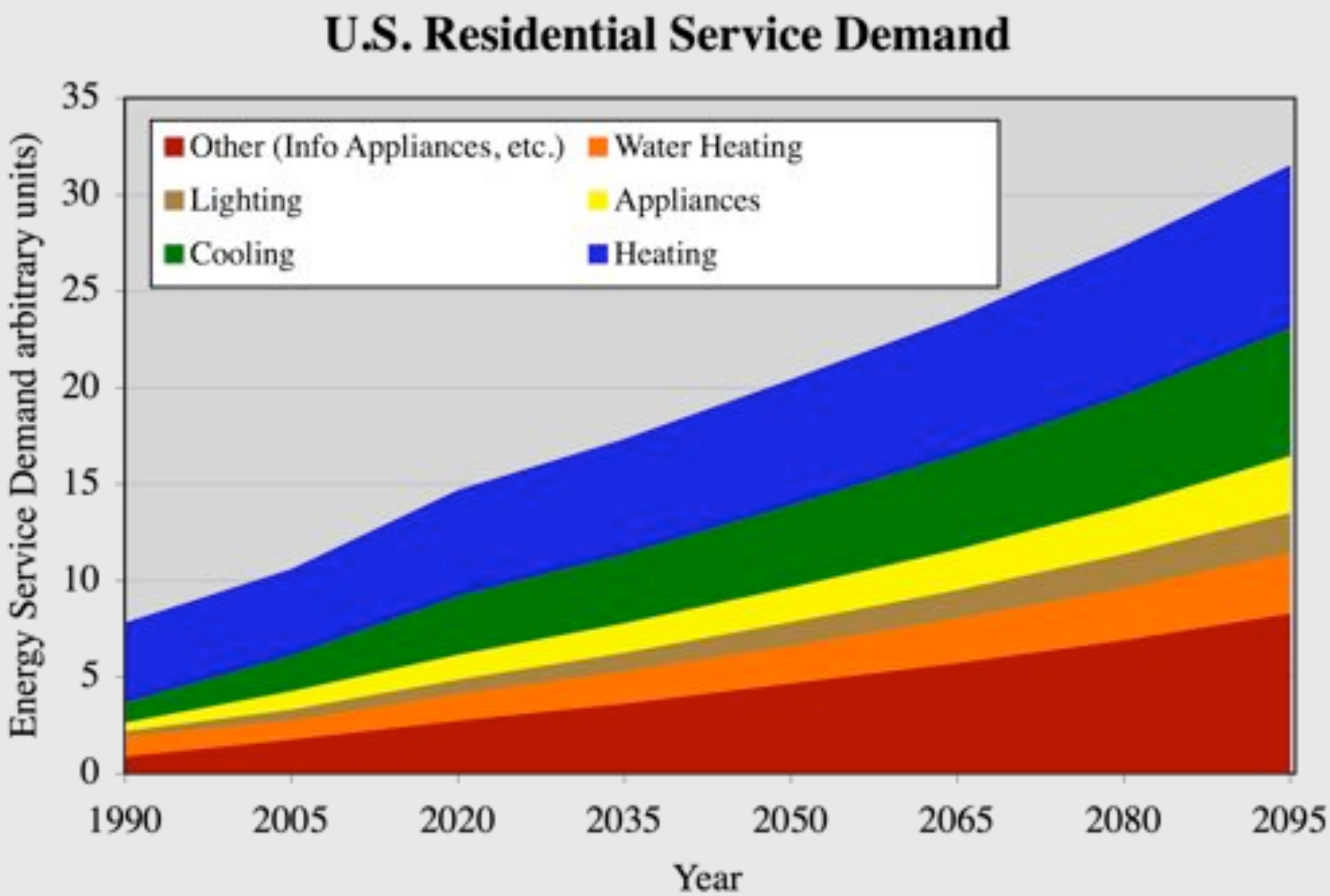
Base Case Cost: $18 Trillion

The value of a technology for climate mitigation needs to be considered over the long term and globally, and depends on the availability of other technologies.

Value of Energy Efficiency in a Climate Context

Increasing Service Demands

Context for Future Energy Consumption



There is a strong historical record of increasing demands on a per-capita basis for floor space and transportation services.

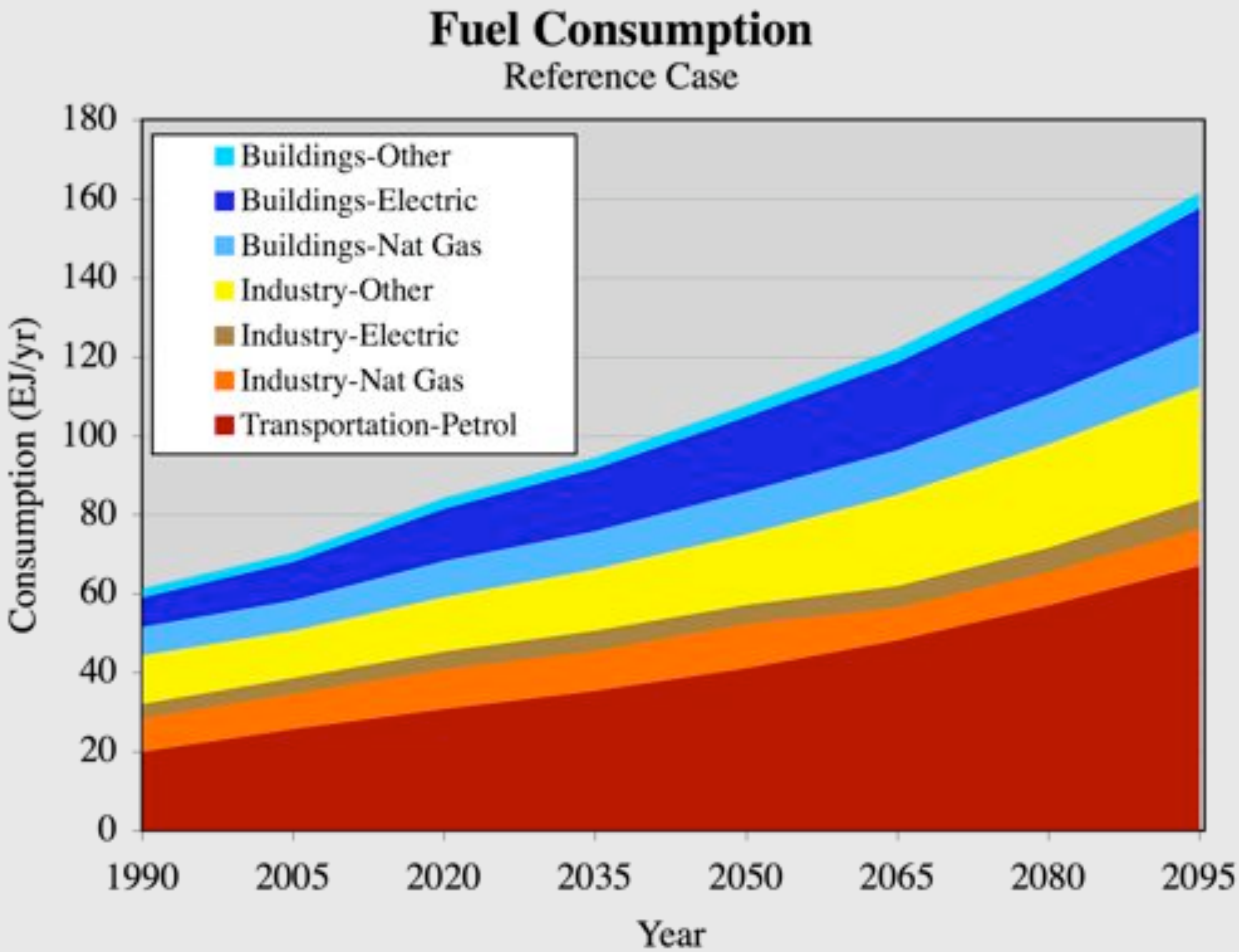
Coupled with population growth, the results in a significant growth in the demand for energy services.

– Heating service grows relatively slowly due to internal gains & increased shell efficiency.

– Cooling increases faster since internal gains add to cooling demand (increases in building shell are also partially negated by increases in internal gains)

– Large growth in "other" demands.

Energy Consumption



– Due to efficiency improvements energy consumption does not increase as rapidly as service demand.
– The share of building and transportation energy use increases with time as these demands grow with population and income.

Technology Scenarios

Three scenarios were constructed.

- **Reference Case**

  Continued technological advance in all end-use sectors. Advances chosen to be at a level that is "likely to occur" with existing policies.

- **Advanced Case**

  Further technological advances are assumed. Research goals for advanced end-use technologies are met allowing cost effective production and deployment.

- **No Tech Change**

  "Strawman" case with no technological advances

  - While this is not a realistic future pathway, this allows us to determine the impact of technological change in the reference case.

In all three cases, technology choices are determined by economic competition (using a logit choice model).

Technology Scenarios

The cost and efficiency of the stock of each end-use technology is specified as a scenario parameter in each year for the reference and advanced cases. For example:

		Reference	Advanced	
Solid State Lighting	2050	122	152	Lumens/W
Solid State Lighting	2095	127	186	Lumens/W
Hybrid Electric Cars	2050	35	58	mpg
Hybrid Electric Cars	2100	39	75	mpg
Industrial Processes	2050	1.05	1.14	-
Industrial Processes	2100	1.09	1.31	-

Technology Scenarios: Residential Building Assumptions

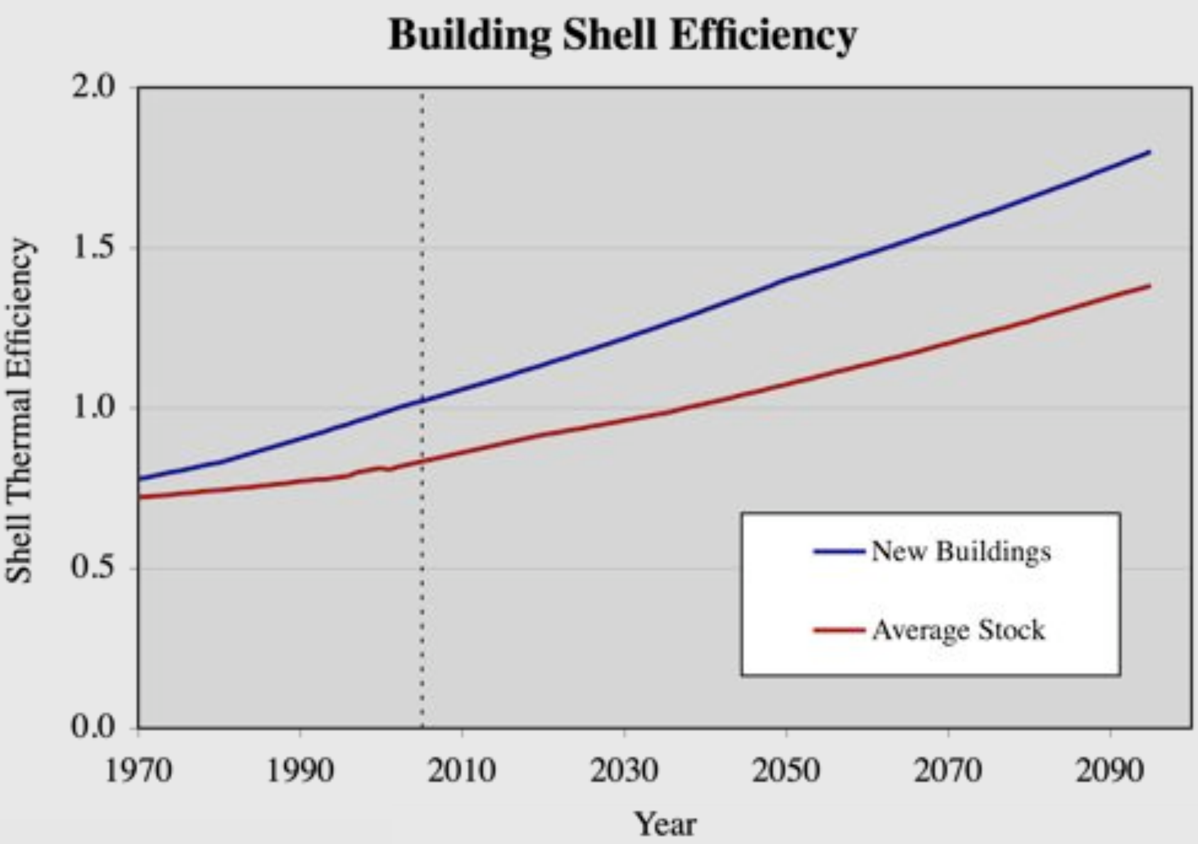
	Historical		Reference		Advanced	
Residential Equipment	**1990**	**2005**	**2050**	**2095**	**2050**	**2095**
Shell efficiency (indexed to 2005)	1.03	1.00	0.81	0.63	0.76	0.47
Heating: energy out/energy in						
Gas furnace	0.70	0.82	0.88	0.91	0.88	0.91
Gas heat pump	na	1.30	na	na	1.67	1.90
Electric furnace	0.98	0.98	0.99	0.99	0.99	0.99
Electric heatpump	1.61	2.14	2.49	2.58	2.82	3.02
Fuel oil furnace	0.76	0.82	0.85	0.87	0.85	0.87
Wood furnace	0.52	0.58	0.66	0.68	0.66	0.68
Cooling: energy out/energy in						
Air Conditioning	2.16	2.81	3.76	3.90	4.18	4.47
Water heating: energy out/energy in						
Gas water heater	0.52	0.56	0.80	0.91	0.80	0.91
Gas hp water heater	na	na	na	na	1.53	1.91
Electric resistance water heater	0.84	0.88	0.95	0.96	0.95	0.96
Electric heatpump water heater	na	na	na	na	2.39	2.51
Fuel oil water heater	0.51	0.55	0.56	0.58	0.56	0.58
Lighting: lumens per watt						
Incandescent lighting	15	15	17	18	17	18
Fluorescent lighting	65	75	100	107	100	107
Solid-state lighting	na	na	122	127	152	186
Appliances and other: indexed to 2005						
Gas appliances	0.96	1.00	1.66	1.72	1.66	1.72
Electric appliances	0.70	1.00	1.42	1.47	1.58	1.80
Gas other	0.99	1.00	1.12	1.25	1.12	1.25
Electric other	1.04	1.00	0.98	1.01	1.42	1.47
Fuel oil other	0.99	1.00	1.05	1.09	1.05	1.09

Building Shell Improvements

The thermal characteristics of the building shell have a substantial impact on energy consumption.

Buildings are long-lived, so important to consider stock effects.

⇒ A stock model of U.S. residential buildings was developed to guide our assumptions on long-term average building stock shell efficiency.

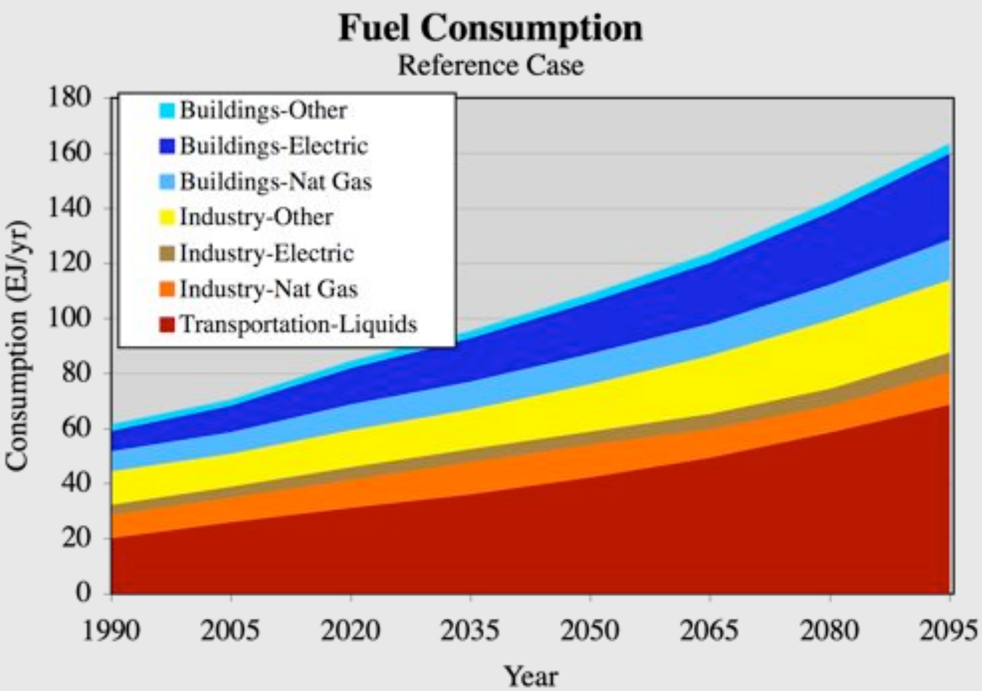


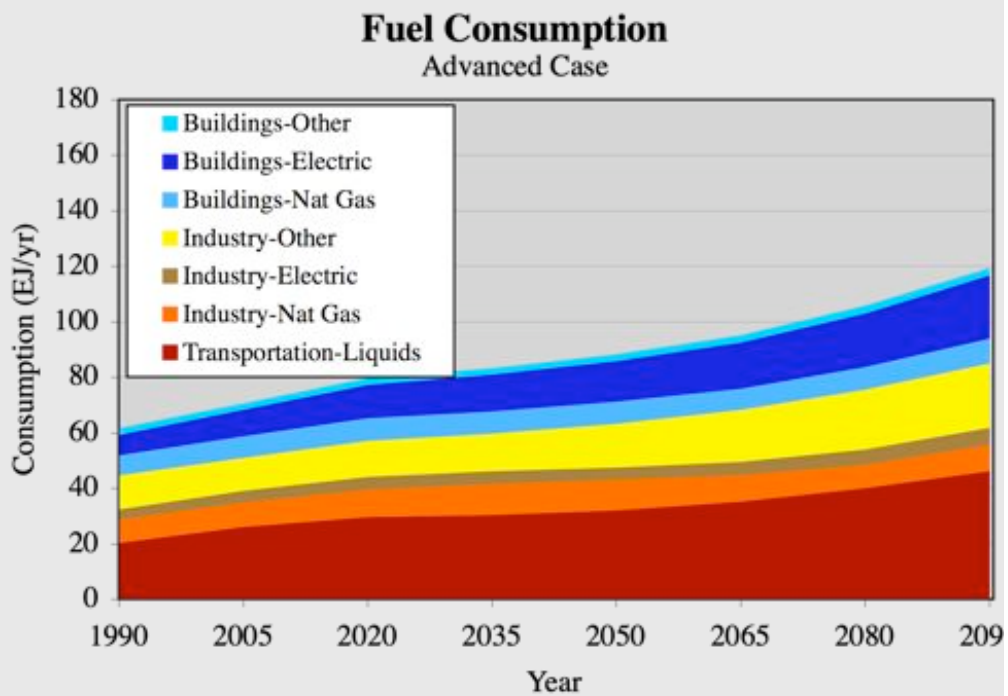
While there is some uncertainty in the past characteristics of building stock, the main effect is that improvements in average stock lag far behind new building improvements.

⇒ Retrofit options may be important (but more expensive)

⇒ Important to understand difference between average and best practice

Energy Consumption: The Impact of Efficiency



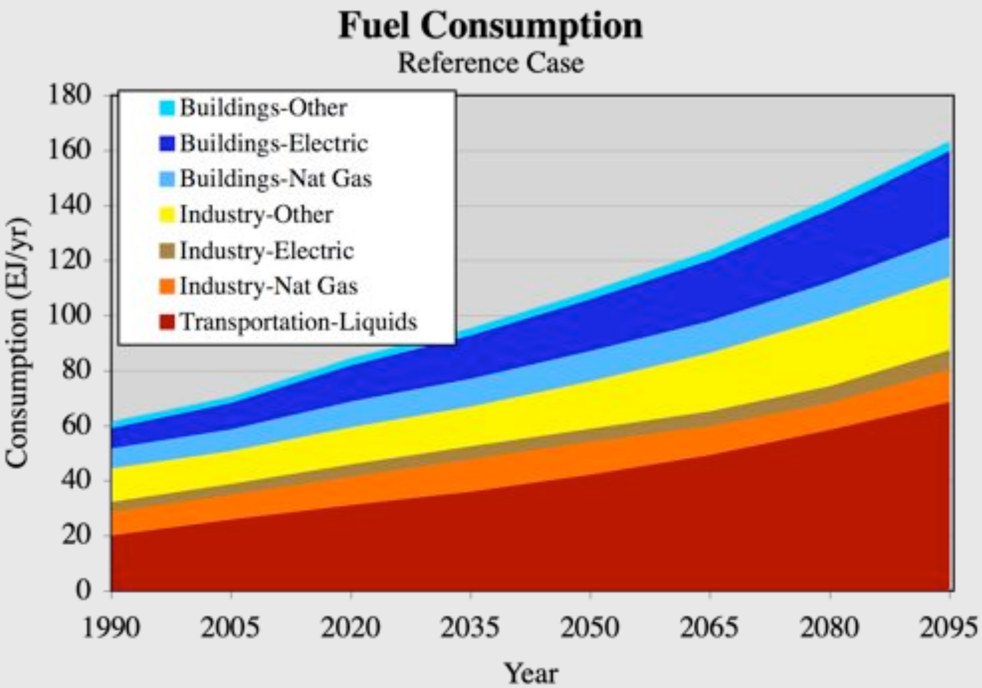


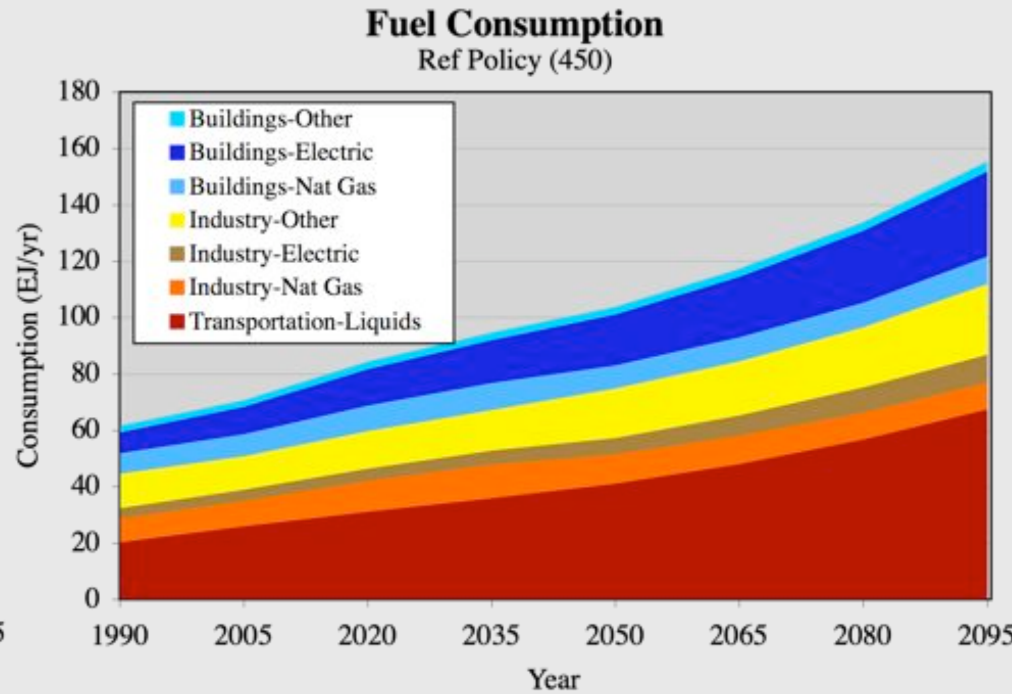
– Energy consumption increases substantially in the reference case.
– More advanced energy efficiency options decrease the growth rate

Even more efficiency could, theoretically, stop energy demand growth, but this is difficult.

It is the stock average chosen by consumers that counts*, not the best performing technology.*

Energy Consumption: The Impact of Climate Policy



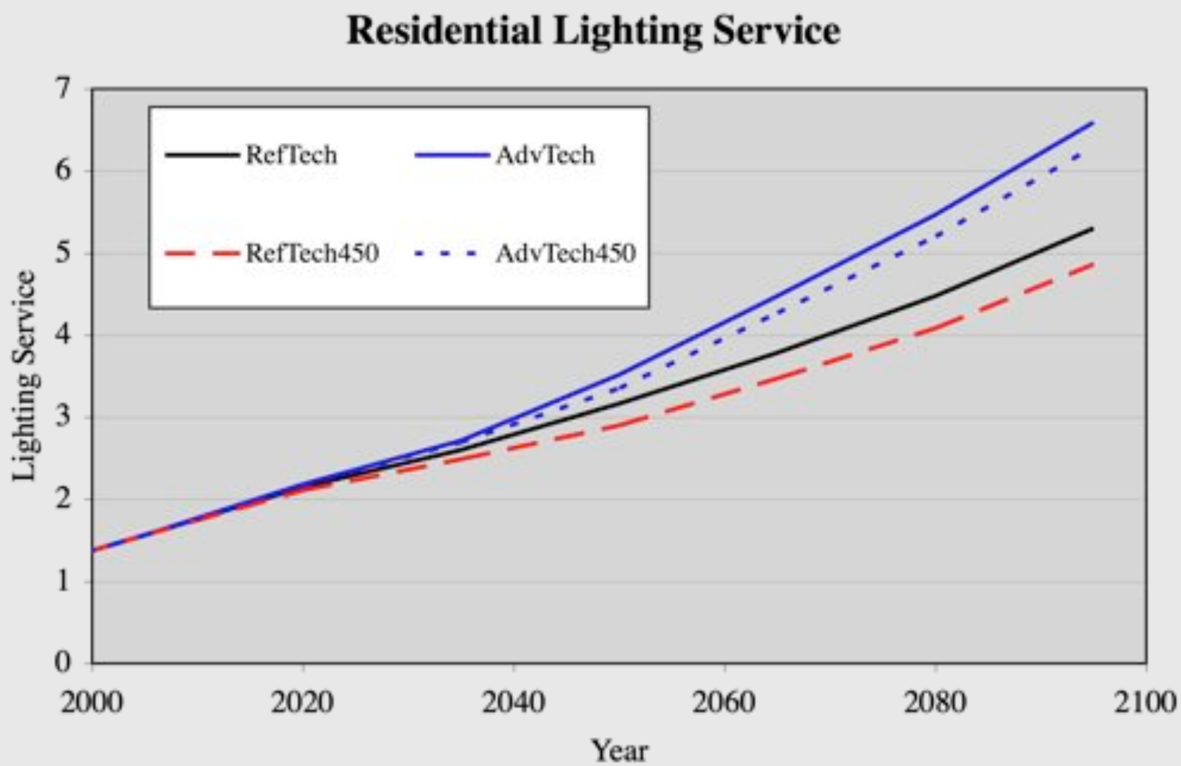


- Under a climate policy the major effect is a switch to electricity, where possible. The transportation sector switches in part to biomass-liquids such as ethanol. This effect seen particularly in buildings and industry.
- This could also happen in the transportation sector with plug-in hybrids (not included in this scenario).
- The consumption of energy services decreases slightly due to higher prices.

Energy efficiency has a potentially much larger impact on end-use energy consumption than climate policy alone.

Energy Service Changes: Climate Policy and Efficiency

Lighting service can be measured, for example, in Lumen-hours.



– More efficient technologies lead to an expansion in technology use.

While the magnitude of the effect is uncertain the sign is known!

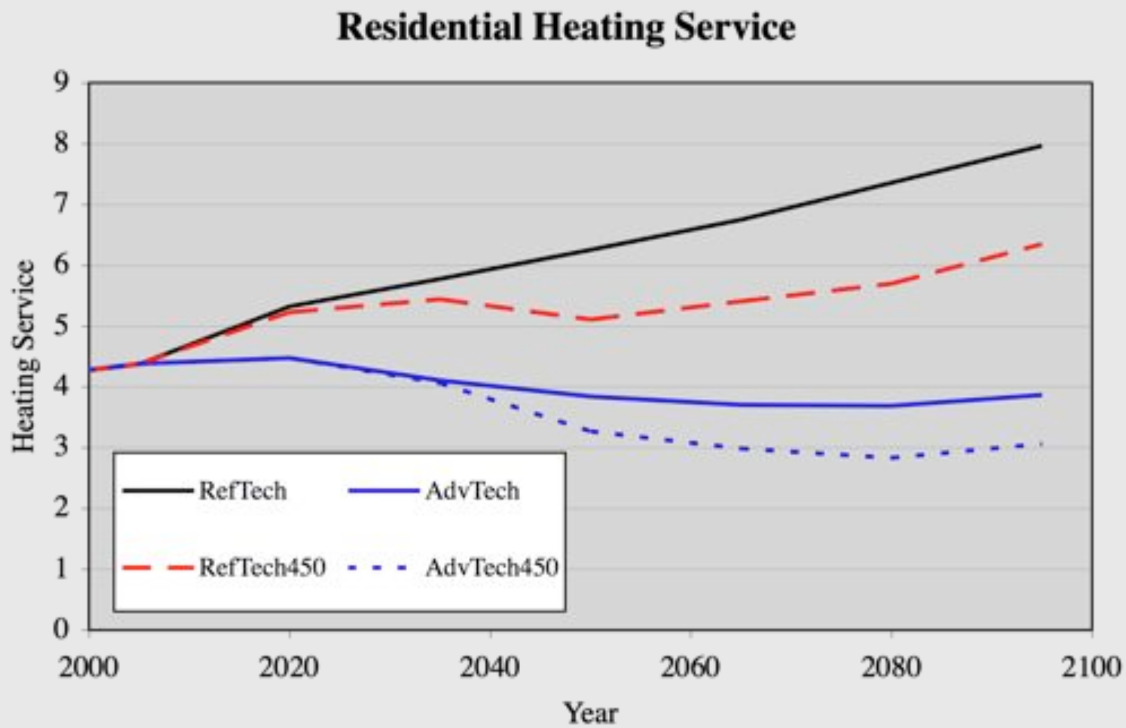
– A climate policy increases prices and reduces demand

Although less so in the advanced case since energy prices have less impact.

And, carbon prices are lower overall.

Energy service demand is not constant across scenarios and technology options.

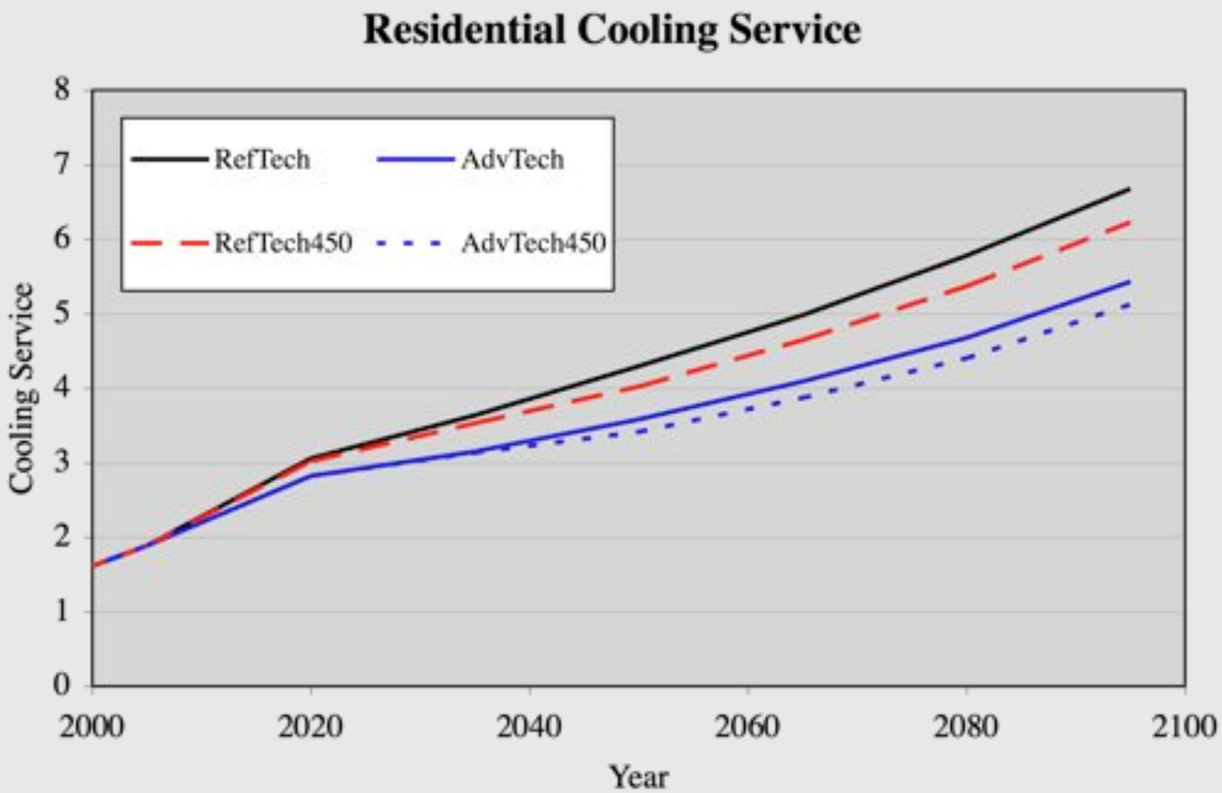
Energy Service Changes: Heating Service



– With heating services, efficiency reduces net service because of the combination of more efficient furnace technology (lowers costs) and improved building shell (lowers inherent need for heating)

– Climate policy effect is similar

Energy Service Changes: Cooling Service



– The changes in cooling service are much smaller overall

Building shell improvements reduce thermal heat flux into the building but also better trap internal gains! So less impact overall.

END OF SLIDES